Vertical root distribution characters of *Robinia pseudoacacia* on the Loess Plateau in China

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Abstracts: On the Loess Plateau, water is the main limiting factors for vegetation growth. Root distribution characters have special ecological meaning as it reflected the utilizations of trees to the environments. Even-aged stands of *Robinia pseudoacacia* on slope lands facing south and north were selected as sampling plots for root distribution investigation. Investigatiing results showed that indicated that on all sites, root biomass decreased with depth, and the distribution depth of fine root was deeper than that of coarser root. The results of variance analysis indicated that there were great differences in root biomass among different diameter classes, and coarser root was the main sources of variance, and the root biomass, especially fine root (φ<3mm) biomass on northern exposition sites was bigger than that on southern exposition sites. Analysis of the vertical root distribution parameters, root extinction coefficient, β indicated that the value of β on northern exposition was more than 0.982, while the value of β on southern exposition was less than 0.982, which indicated that the vertical root distribution depth of *Robinia pseudoacacia* on southern exposition was deeper than that on southern exposition. And the distribution depth of fine roots (Φ<1mm) was deeper than that of thicker roots(Φ<3mm), which was in favor of the uptake of water and nutrients from deeper layers, helped the trees to adapt the arid environment, and promoted the growth of the upper parts of the tree.

Keywords: Root diameter classes; Variance analysis; Root extinction coefficient; Vertical distribution characters; Site conditions; Loess Plateau

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Introduction

Root sytrunk is the main organ for vegetation to absorb water and nutrient, its form and distribution characters directly reflected the utilization of trees to the local site conditions (Böhm 1979). To study the vertical root distribution characters, Gale & Grigal presented a model of vertical root distribution based on the following asymptotic equation:

$$Y=1-\beta^{d} \qquad (1)$$

Where Y is the cumulative root fraction (a proportion between 0 and 1) from the soil surface to depth d (cm), β is the fitted root extinction coefficient. β is the only parameter estimated in the model and provides a simple numerical index of relative rooting distribution. High β values correspond to a greater proportion of root at depth and lower β values imply a greater proportion of roots near the soil surface (Böhm 1979; Jackson *et al.* 1996; Stone and Kalisz 1991). Researches (Gale and Grigal 1987; Jackson *et al.* 1996; Stone and Kalisz 1991) also revealed that species at different succession stages showed different root distribution patterns. It has verified (Jackson *et al.* 1996; Stone and Kalisz 1991) that for vegetation succession, pioneer species of early stages showed deeper rooting depth than that of the climax and sub climax species, and tended to have more root in deeper soil compared to that of the climax and sub climax species, which are of great importance by ameliorating and improving the soil physical and chemical conditions for later species. Ages of tree and soil properties also have effect on the root shape and distributions (Sainju and Good 1993), which were reflected in the difference of vertical root distribution characters. Lyr and Hoffman (1967) thought that roots of trees can reach its maximum depth during the initial years after planting, as to the *R. pseudoacacia*, its vertical distribution depth of roots could reach 3.7 m in 4 years after planting. Coile (1936) also verified that although the root density increased with age, it reach its distribution maximum both in vertical and horizontal directions, which implied that its root distribution model was established in early stages. It has been assumed that root genetic characters and its soil environmental factors together controlled its distribution characters. As site conditions was the more inconstant, there were differences in root distribution characters on different site, which were exhibited in the difference of the value of the β.

R. pseudoacacia was the main species for soil and water conservation. It has large root sytrunk without remarkable taproot, and has once been considered a shallow-rooted species (Lliu *et al.* 1987). Recent studies have verified that *R. pseudoacacia* is one deep-rooted species on the Loess

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Plateau, with more roots in deeper layer of the soil (Zhao *et al.* 2000). Studies (Shao 2000) on the Loess Plateau have verified that water is the main limiting factors for vegetation growth, most water came from local rainfall and there was almost no underground water in soil within hundred meters. Slope directions were the main factors influencing water distribution by changing the time of sunshine on different site. In addition, most soil matrix on the Loess Plateau was loess, and its depth is over hundred meters. Thus, slope direction was the main factors when considering site types division.

The objective of this article was to analysis the vertical root distribution characters of *R. pseudoacacia* on the Loess Plateau, determine its vertical distribution characters and parameter, and try to find out its relationship with the local growth conditions. Also, it may provide useful information for the root studies and local ecological construction.

Material and method

Study area

As most valleys in this area run from east to west, or north to south, two valleys were selected as sampling plots for root investigation. One is Nihe Gully, running from north to south; the other is Qinzhuang Gully, running from west to east. Both the two gullies were located in Chunhua County on the Loess Plateau with an altitude ranging from 630 m to 1809 m. Soils include two zones with the main soil types of Calcic cinnamon soils and loess. Soil fertility is lower as the organic matter content is under 1%. The average annual temperature is 9.6 °C, with an average temperature in January of -4.3 °C, and 23.1 °C in July. The average annual precipitation is 600.6 mm, with a maximum of 822.6mm and a minimum of 409.5 mm. The average rainfall in the growing season is 454 mm. Most hillside lands are facing south and southwest, which allows them to have more chances for the sunshine, and leads to intense evaporation of the water.

Sampling method

In this study, even-aged stands of *R. pseudoacacia* on slope land facing south and north respectively (general information of the stands was shown in the Table 1) were selected as sampling plots for root distribution investigation. In each stand, average tree height and diameter at breast height were determined by measuring tree height and breast-height diameter of 30 trees randomly selected, among which 4 trees closest to the average height and breast-height diameter of the stand were selected as standard trees for root investigation. To each of the 4 standard trees, 1/4 circle around the tree was determined as sampling section according to the direction distribution (see Fig. 1). Thus, the root distribution characters of 4 trees in the same stand were investigated to represent the general root distribution information of one complete tree in the stand after calculation. And when sampling, three points evenly on the radius 0.5 m and 1.5 m respectively were determined as sampling points. On each point, soil auger (φ=6.8 cm) was used to drill on each layer of 10 cm until there is no root in soil

Table 1. A brief view of sample areas of survey for root sytrunk of *R. pseudoacacia* at Chunhua County

No.	Place	Exposition	Gradient	Position on slope	Soil species*	Stand age (year)	Average height /m	Average DBH /cm
1	Nihe gully	SW	23	Middle	YLS	10	8.31	8.8
2	Nihe gully	E	9	** Under	YLS	10	8.85	9.3
3	Qinzhuang gully	E	31	Middle	OL	24	12.25	15.2
4	Qinzhuang gully	EN	31	Middle	YLS	24	12.58	16.3
5	Qinzhuang gully	W	33	Middle	YLS	24	11.91	13.3
6	Qinzhuang gully	WS	26	Middle	OL	24	12.38	13.2

* LS = yellow loessial soil, OL = old loess; ** under: This stand was formed after landslide.

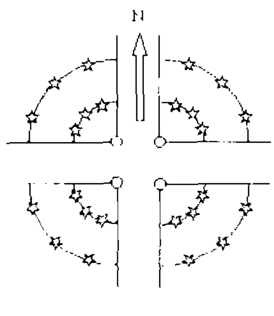

Fig. 1 Sketch map for root investigation

"☆" is the sampling points on 0.5m and 1.5m to the trunk respectively; "O" is the sampling trees.

Root selected from the soil of each layer was taken back laboratory in the plastic bag after numbering. Then they were classified into 4 grades according to φ<0.5 mm, 0.5 mm ≤φ< 1 mm, 1 mm ≤φ< 3 mm and φ ≥ 3 mm. Roots of each single class from each layer were weighed after they were dried in the oven at 105°C for over 8 h. Root from each tree of different direction was pooled and calculated to determine the tree root distribution characters.

Almost at the same time, researches on the dynamics of soil moisture were carried out. According to the schedule, soil samples were taken from each 10 cm layers on soil profile (0-400 cm) by soil auger (φ=4.0 cm), and its moisture content were determined by oven-drying at 105°C for 8

hours.

Results and discussion

Statistical analysis

From Table 2, it was clear that on all sites, variances of root biomass increased with diameters. Coarser root (φ>3 mm) was the main source of such variance. Results (Table 2) also indicated that there were great differences of different diameter root biomass on all sites. Variance analysis results of root biomass from the same depth of the 4 standard trees indicated that there was little variance to finer root (φ ≤0.5 mm; 0.5<φ≤ 1mm; 1<φ≤3 mm), what's more, such variance decreased in deeper soil. But to coarser root (φ>3 mm), because of the randomicity of root sampling and the uncertainty of root distribution, there was great differences in its distribution range. Analysis of root biomass distribution on different distances on the whole profile indicated that the bigger root diameter, the bigger its biomass and variance among soil depth.

Table 2. Summary of average and its variance of root biomass of *R. pseudoacacia* of different diameters on different sites

Sampling plots	Distance /m	φ≤0.5 mm		0.5<φ≤1 mm		1<φ≤3 mm		φ>3 mm	
		Average (g)	Variance	Average (g)	Variance	Average (g)	Variance	Average (g)	Variance
Nihe gully -1	0.5	0.019	0.003	0.026	0.002	0.131	0.036	0.371	1.519
	1.5	0.013	0.001	0.022	0.002	0.104	0.028	0.237	0.379
Nihe gully -2	0.5	0.023	0.015	0.023	0.002	0.077	0.025	0.483	1.145
	1.5	0.008	0.000	0.012	0.001	0.057	0.023	0.154	0.296
Qinzhuang gully -R-W-N	0.5	0.007	0.000	0.025	0.001	0.058	0.013	0.331	0.696
	1.5	0.008	0.000	0.017	0.001	0.059	0.020	0.208	0.365
Qinzhuang gully -R-W-S	0.5	0.005	0.000	0.010	0.001	0.045	0.008	0.421	1.698
	1.5	0.002	0.000	0.008	0.000	0.037	0.006	0.508	2.556
Qinzhuang gully -R-E-N	0.5	0.003	0.000	0.017	0.001	0.034	0.008	0.301	1.197
	1.5	0.010	0.000	0.019	0.001	0.068	0.015	0.241	0.479
Qinzhuang gully -R-E-S	0.5	0.008	0.000	0.026	0.014	0.049	0.008	0.226	0.405
	1.5	0.007	0.000	0.020	0.001	0.100	0.020	0.228	0.501

Vertical root distribution characters of different diameters

Generally, root biomass distribution of each diameter class decreased with the increase of soil depth (Fig. 2), especially on southern exposition site. In this study, the distribution depth of fine root can reach 1.9 m, but its biomass was small. It was also clear that from Fig 2, there were great differences in vertical root biomass distribution on different sites. To the young stands (Nihe gully -1, Nihe gully-2), because the effect of interactions between soil conditions and root was not so intensive, their root distributions did not have remarkable differences. But to mature stands, there were clear differences. On southern exposition site (Qinzhuang gully -R-W), the root biomass at 1.5 m to the trunk was smaller than that at 0.5 m. What's more, the distribution depth above that the accumulative root biomass accounted for over 95% of the total also decreased from 1.2 m (0.5 m to the trunk) to 0.8 m (1.5m to the trunk). On northern exposition sites (Qinzhuang gully -R-E), things were different. The root biomass at 1.5m to the trunk was bigger than that at 0.5 m, and the distribution depth above that the accumulative root biomass accounted for over 95% of the total also decreased from 1.4 m (0.5 m to the trunk) to 1.1 m (1.5 m to the trunk). Most important of all, the biomass of fine root (φ≤3 mm) on northern exposition site was bigger than that on southern exposition site, which again confirmed that trees on northern exposition sites can adapt better to droughty climate.

Vertical root distribution parameters of different aspect of slope

Current studies have verified that the main function of coarse root was the mechanic support to the trees, while its main absorption was completed by fine root. Although there is no accepted definition to the fine root (Marashall and Waring 1985; Ronald *et. al.* 1993), which the root with its diameter less than 1 mm was fine root was accepted by most root researchers (Farrish 1991; Marashall and Waring 1985). Zhao *et al.* (2000) has verified that coarser root (φ=2.5mm) could still maintain higher vigor in the soil with less moisture content (<7%), that is, such root are still absorptive. Thus to make the results more comparable, root biomass with its diameter less than 1 mm and 3 mm (including the root with its diameter less than 1 mm) respectively were calculated by incorporation to illustrate the vertical root distribution characters.

Based on the results from calculation and analysis, it was clear that the accumulative root biomass distribution characters was in accordance to that in equation (1) with higher correlation coefficient, which indicated that the root extinction coefficient was better in describe the characters of vertical root distribution, and the difference in the value of β visually and directly reflected the difference in root vertical distribution characters.

It was clear from Fig. 3 that the roots biomass of *R. pseudoacacia* both on northern and southern exposition slope decreased with the increase of depth. Most of the

roots (accounting for over 90% of all the root biomass) concentrated in the upper soil of 0-100 cm. Hereinto, the root distribution depth of *R. pseudoacacia* on northern exposition slope was all deeper than that on the southern exposition slope, that is, the root distribution parameter β on northern exposition slope is bigger than that on southern exposition slope, which helps to demonstrate that the root of *R. pseudoacacia* on northern exposition slope is more helpful when utilizing soil moisture in deeper layer.

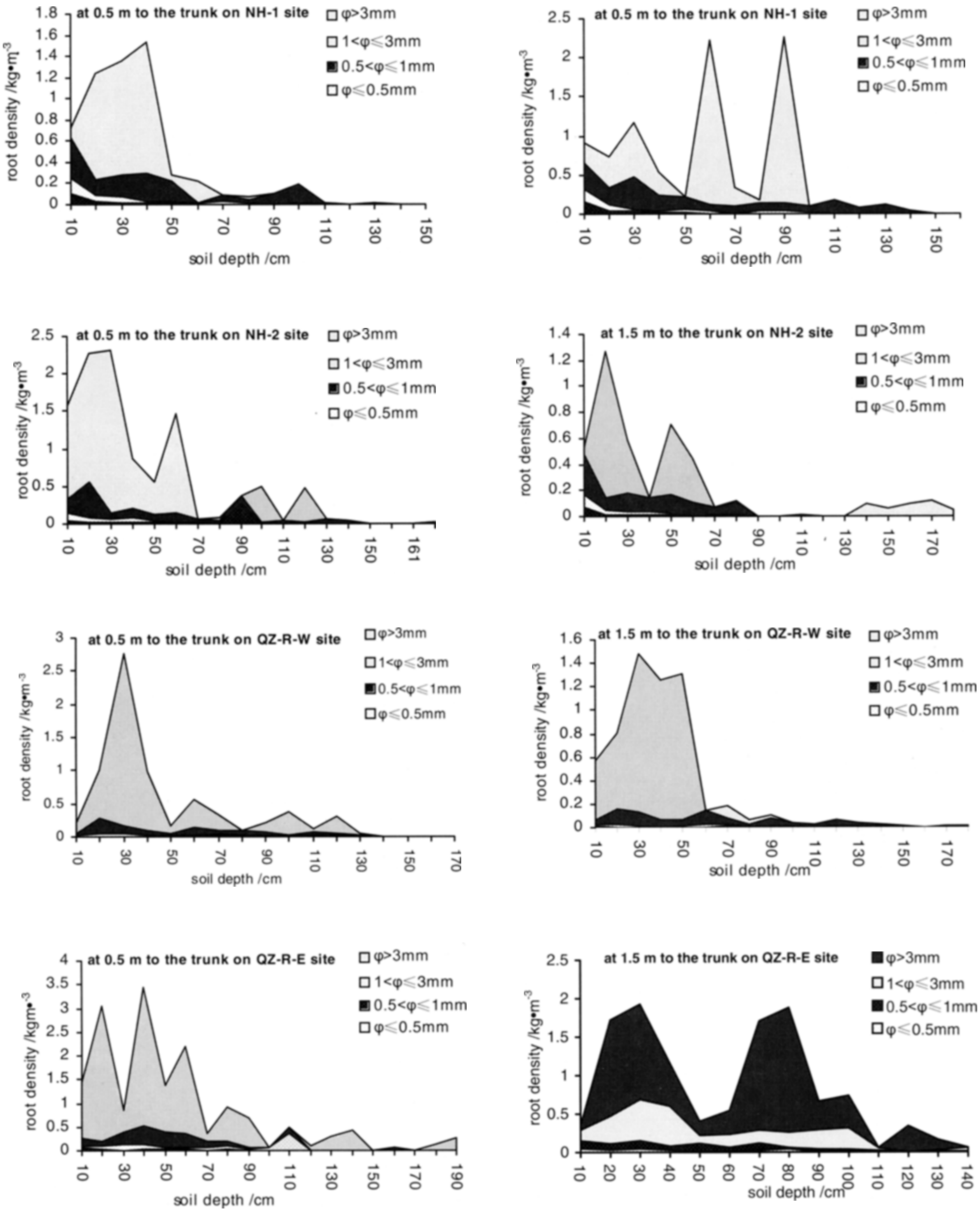

Fig. 2 Root distribution of *R. pseudoacacia* on different sites

Note: NH---- Nihe gully; QZ---- Qinzhuang gully.

Comparisons of roots with different diameters on the 2 areas both indicated that root distribution depth of fine root (φ<1 mm) is deeper than that of coarser root (φ>1 mm). That is, the vertical root distribution parameter, β, of fine root (φ<1 mm) is bigger than that of coarser root (φ>1mm), which helps to explain that the trees on north slope can be more efficiently in utilizing soil moisture from deeper soil than that on south slope.

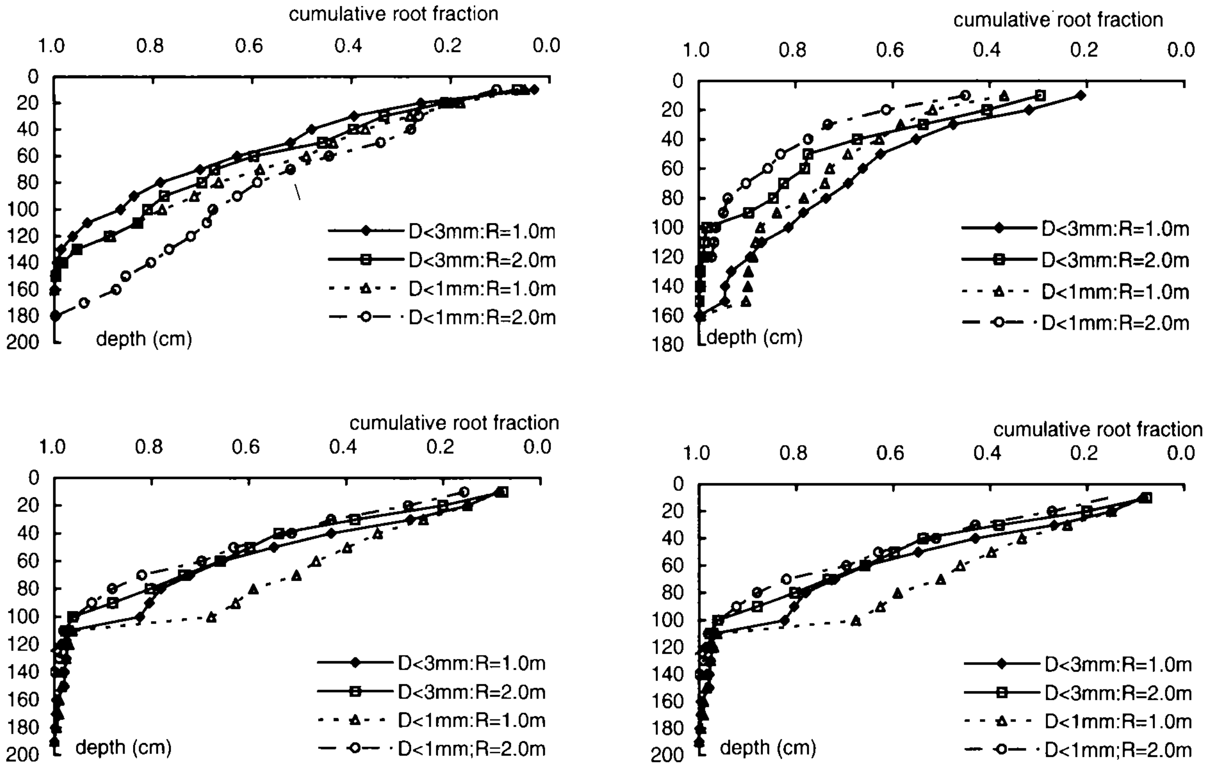

Fig. 3 Root distribution parameter of different diameter class at different distance to the trunk on NH-E, NH-SW, QZ-W, QZ-E plots.

(Noting: In the Fig, D is the root diameter, and R is the distance of sampling points to the trunk.)

Table 3. The value of root distinction coefficient of *R. pseudoacacia* —β on slopes of different directions

	Northern exposition slope				Southern exposition slope			
	*NH--E		**QZ-- E+EN		***NH--SW		****QZ—W	
	R=1.0m	R=2.0m	R=1.0m	R=2.0m	R=1.0m	R=2.0m	R=1.0m	R=2.0m
φ<3	0.982	0.974	0.982	0.983	0.980	0.974	0.982	0.980
Relevant coefficient	0.994	0.992	0.996	0.996	0.992	0.990	0.993	0.995
φ<1	0.983	0.968	0.987	0.988	0.984	0.967	0.986	0.981
Relevant coefficient	0.989	0.996	0.995	0.985	0.970	0.995	0.971	0.995

*NH-E is the results from sampling plots facing east in Nehe Gully; **QZ-W is the results from the sampling plots facing west in Qinzhuang gully; ***NH—SW is the results from sampling plots facing westeast in Nehe Gully; ****QZ—E+EN is the results from sampling plots facing west in Qinzhuang gully.

From Table 3, it was clear that there was difference in the value of β at different distance to the trunk. To the mature stands, on the northern exposition slope, the rooting depth of *R. pseudoacacia* at 2.0 m distance to the trunk is deeper than that at 1.0 m distance to the trunk; while on the southern exposition slope, the rooting depth of *R. pseudoacacia* at 2.0 m distance to the trunk is shallower than that at 1.0 m distance to the trunk. The different root distribution pattern on northern and southern exposition slope indicated that the root on northern exposition slope can be extended to larger space in vertical and horizontal direction, which means that root on northern exposition slope can afford more water and nutrient for the need of tree growth, thus trees on northern exposition slope show higher productivity. This is verified by the main indexes of tree growth on every stand: both the average height and average breast height on northern exposition slope is bigger than that on southern exposition slope.

Conclusions and discussion

It has verified both in researches and practice that the root

distribution characters is of great importance to the upper part growth of the trees. The relationship between root distribution characters and planting density also is an important problem to the practice of planting trees. As the Loess Plateau located in the central of the Asia continent, water is the main limiting factor to the development of agriculture and forestry (Sun *et al.* 1998). Long-term observations on soil moisture of forestland have verified that there existed a sharp decrease of soil moisture in certain layers of the soil profile, i.e., the desiccation layer. It has so serious negative effect on plant growth that some mature trees even died in droughty years. As most water for vegetation growth came from precipitation, and the utilization of the precipitation depended on the ability of soil holding water and the efficiency of tree species utilizing water, the vertical root distribution characters tree species is of great importance for trees to utilizing soil moisture. As the trees root distribution parameters on northern exposition slope is bigger than that on southern exposition slope, it has larger space for water and nutrient absorption. Based on this study and results from others, the author thought that the tree density on northern exposition slope should be bigger than that on the southern exposition slope to improve the water and nutrient acquisition.

Based on the results of the vertical root distribution parameters, root extinction coefficient, β, of *R. pseudoacacia* on the Loess Plateau, following conclusions can be reached:

On all sites, root biomass of different diameter decreased with the increase of root distribution depth, and the distribution depth of fine root was deeper than that of coarser root. Vertical root distribution characters on northern exposition site were favor of the utilization of soil moisture, and help the trees adapt better in droughty climate.

Results of variance analysis of vertical root distributions indicated that coarser root was the main source of variance of vertical root distributions. On northern exposition site, the variance of spatial root distribution was relative small, which indicated the vertical root distributions were well proportioned. What's more, its root distribution depth was deeper than that on southern exposition sites. Such root distribution characters was propitious for trees to utilize soil moisture stored in deeper soil layer, and improved the adaptability of trees to droughty climate. While on southern exposition sites, most of its root (95% of the total) was concentrated in 100cm on soil profile, and the variance among depth was bigger.

On different site, the vertical root distribution parameter shows remarkable difference. All the value of *β* on northern exposition slope is bigger than 0.982; While it is smaller than 0.982 on southern exposition slope, which indicated that the root distribution depth on northern exposition slope is deeper than that on the southern exposition slope, and is more helpful for trees to utilize soil moisture in deeper layer. In the mature stands, on northern exposition slope, the value of β at 0.5m to the trunk was 0.982 (φ<3mm) and 0.987 (φ<1 mm) respectively; and the value of β at 1.5 m to the trunk was 0.983 (φ<3 mm) and 0.988 (φ<1mm) respectively. While on the southern exposition slope, he value of β at 0.5 m to the trunk was 0.982 (φ<3 mm) and 0.986 (φ<1mm) respectively; and the value of β at 1.5 m to the trunk was 0.98 (φ<3 mm) and 0.981 (φ<1 mm) respectively. All the data illustrated that the root on northern exposition slope has larger distribution space, both in vertical and horizontal.

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Reference

Böhm, W. 1979. Methods of studying root sytrunks [M]. New York: Springs Berlin Heidelberg

Sun Changzhong, Huang Baolong, Chen Haibin, Liu Zengwen, Wen Zhongming. 1998. Interaction between soil water condition and different kinds of artificial plant cover in the Loess Plateau [J]. Journal of Beijing Forestry University, **20**(3): 7-14

Coile, T.S. 1936. Distribution of forest tree roots in North Carolina Piedmont soils [J]. J. For. **35**: 247-257

Farrish K.W. 1991 Spatial and temporal fine-root distribution in three Louisiana forest soil [J]. Soil Sci. Soc. Am. J. **55**:1752-1757

Gale. M.R, Grigal, D.F. 1087. Vertical root distribution of northern tree species in relation to successional status [J]. Can. J. For. Res., **17**: 829-834.

Jackson, R.B., Canadell, J., Mooney, H.A. 1996. A global analysis of root distribution for terrestrial biomes [J]. Oecologia, **180**:3 89-447.

Lliu Bingzheng, Wang Youmin, Li Kairong. 1087. Preliminary studies of the effect of R. pseudoacacia on soil promotion [J]. Journal of Northwest Forestry College, **2** (1): 48-57

Lyr, H. and Hoffmann, G. 1967. Growth rates and growth periodicity of tree roots [J]. Int. Rev. For. Res., **2**: 181-236.

Marashall, J.D., Waring, R.H. 1985. Predicting fine root production and turnover by monitoring root starch and soil temperature [J]. Can. J. For. Res., **15**: 791-800

Ronald, L., Hendrick, Kurt S. Pregitzer. 1993. The dynamic of fine root length, biomass, and nitrogen content in two northern hardwood ecosytrunk [J]. Can. J. For. Res., **23**: 2507-2520.

Sainju, U.M, Good, D.E. 1993. Vertical root distribution in relation to soil properties in New Jersy Pineland forest [J]. Plant and Soil, **50**: 87-97.

Shao Ming'an. 2000. Soil moisture researches on the Loess Plateau [M]. Beijing: Scientific Press.

Stone. E.L, Kalisz. P.J. 1991. On the maximum extent of tree roots [J]. For. Ecol. Manage., **46**:59-102.

Zhao Zhong, Li Peng, Wang Naijiang. 2000. Researches on root drought-resistance of main species for forestry on Weibei Loess Plateau [J]. Researches of Soil and Wataer Conservation, **7**(1):92-94

Zhao Zhong, Li Peng, Wang Naijiang, 2000. Researches on the root distribution characters of main tree species for silvicuture on the Weibei Loess Plateau [J]. Journal of Applied Ecology, **11** (1): 37-39 (in Chinese)